Improvements on Sensitivity Repeatability of Polarization Maintaining Optical Fibre Sensor Using Computer Blob Detection and Tracking

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Received 17 Jan, 2014; Accepted 25 Feb, 2014; Published 10 Apr, 2014

Abstract

Improvements on sensitivity resolution of Polarization Maintaining optical fibre sensor based on evanescent field interaction have been achieved by image processing and tracking of transversally immersed polarization maintaining optical fibre probe on HF acid. Etching rates of fibre dopants are tracked in real time and injected in an algorithm for real time simulation of the Polarization Maintaining optical fibre sensor. Resolution sensitivity better than 0.2 dB has been achieved, allowing a high degree of repeatability of Polarization maintaining optical fibre sensors.

Keywords

Sensors; Fibre; Evanescent Field; Polarization; Image Processing

Introduction

Optical fiber evanescent sensors are very important devices for detecting a high diversity of physical or chemical analytes. Optical fiber evanescent sensors currently show a high degree of performances due to their mechanical flexibility. The optical performances of such devices mainly due to the intrinsic low attenuation properties of optical fibers make them very attractive to use In general, optical fiber evanescent sensors are based on the interactions between evanescent field of the sensing fibers and the analyte. In order to expose the evanescent filed of the fiber to the analyte, the fiber cladding is often removed and the fiber core is surrounded by the detecting material. Several kinds of optical fibers have been used for both chemical and physical analytes detection. Sensors based on multimode optical fiber exhibit a limited resolution mainly due to modal noise causing the strength of the interaction between the fibers guided light wave and the analyte to fluctuate. Single mode fibers have shown better performances. However light wave polarization fluctuation during its propagation in the fiber is a limiting factor, particularly for optical sensors based on the excitation of surface Plasmon (SP). In that case, polarization of light in the optical fiber needs to be precisely controlled to ensure stable interaction and to avoid output fluctuations. Polarization Maintaining Optical Fiber have been used to overcome output sensitivity to light polarization Most of evanescent sensing Polarization Maintaining optical fibers are based on polishing [1, 2] or chemical etching [3]. In polishing technique, the fiber is glued into a curved slot in a silica block such that the polarization axis of the fiber is normal to the silica blocks surface. However, fiber alignment cannot be controlled precisely even by using the elasto-optic method [4]. The error of alignment of fiber birefringent axis with respect to the surface of the silica block surface is estimated to be within 1 degree, which limits polarization diversity sensitivity to -35 dB. The chemical etching method is undoubtedly the simplest and the most inexpensive optical fiber evanescent fabrication technique. Chemical etching of polarization maintaining optical fiber, owing to its ease of operation and polarization axis alignment preservation is preferred to the polishing method. The etching depth is the main factor that determines the interaction strength of guided light wave and the analyte. Hence, etching depth has to be precisely controlled in order to optimize the sensing system sensitivity and performances according to their applications. However, the relationship between the etching depth and etching

parameters (e.g. nature and concentration of etchant, choice of organic solvent, etching temperature…) is not clear, and there is no technique that is both simple and effective that can control the shape of the etched fiber. The strong dependence of the sensitivity of interaction between light wave and analyte requires robust methods for controlling the etching depth. Various methods have been reported to control etching depth of silica optical fiber [5, 6] and D-shape optical fiber [7]. However none of these methods can be applied to control etching process of Polarization Maintaining optical fiber.

In this paper, we present a simple, novel, repeatable and controllable approach to fabricate Polarization Maintaining Optical fiber evanescent sensor. The method consists on continuous real time experimental measurement of etching rates of both cladding and stress rods during the etching process of the Polarization Maintaining optical fiber sensor by using a transversally immersed optical PM fiber probe in acid. The approach is based on microscopic image acquisition of this polarization maintaining optical fiber probe during etching process with correlation tracking of the fiber cladding and stress rods. Image processing with blob detection analysis and centroid tracking allow precise determination of etching speeds. Calculated etching rates are then used for real time simulation of the optical fiber shape by using diffusion equations. This method allows repeatable and controllable fabrication of evanescent sensing PM fiber even in a variable environment. By using this method, a high sensitivity repeatability with resolution better than 0.2 dB have been achieved for the fabrication of polarization maintaining optical fibre sensors fabrication, even on a variable environment.

Experimental Set up

The optical fibers used in this study were PANDA-type Polarization Maintaining Optical fibers with a Ge-doped core, pure silica cladding and Bore-doped stress rods. The core of the optical fiber diameter was 10 um and the cladding of the optical fiber was 125 um. Before dipping into HF solution, roughly 1.5 cm of the polyacrylate coating was stripped away by a fiber stripper, and then the fiber was cleaned by ethanol to remove the debris from the jacket. A fiber cleaver cut the fiber into 1 cm lengths and then the even end of the fiber was selected to be studied under optical microscopy. The cut fiber was perpendicularly immersed into a hydrofluoric acid etching solution. Figure 1 shows the schematic of the experimental set up.

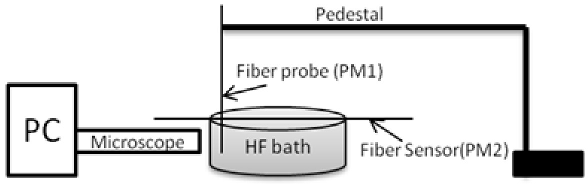

FIG.1 EXPERIMENTAL SET UP

A Teflon beaker contained hydrofluoric acid and the prepared optical fiber probe (PM1) perpendicularly immersed into it. The probe (PM1) is periodically observed using a microscope connected to a PC station. A simple tracking algorithm of both cladding and stress rods regions allow calculation of cladding and stress rods etching rates (figure 2). Images are taken every 20 seconds and calculated etching rates are then used in a simple algorithm to simulate the shape of an etched polarization maintaining optical fiber (PM2) which is incorporated in the same HF bath as PM1. This approach is mainly based on the fact that both etching rates (cladding and stress rods) are characterized simultaneously by chemical etching of perpendicularly immersed fiber probe PM1. Images processing are performed using computer vision methods. Blob detection is designed to identify the etched optical fiber probe. In typical applications of using blob analysis, blob's area, diameter, shape, location and perimeter are significant features need to be calculated. In processing, blob detection function mainly considers to identify the same gray level pixels from the image. These pixels are separated into different blobs based on relationship of inter-connection. Figure 2 shows the flowchart of image manipulation procedure.

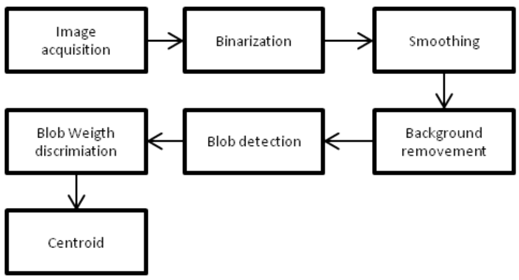

FIG.2 FLOW CHART OF OPTICAL FIBER IMAGE PROCESSING

A PC station allows processing of PM1 probe microscopic images by using algorithms based on blob detection. Firstly, the original image captured by camera should be converted into mono image (fig 3). A non etched optical fiber image is used as the background (fig 3.a.1). Figures 3.b.1 and 3.c.1 are images of HF chemical etching of PANDA-type

polarization maintaining optical fiber. The chemical etching of stress rods appears clearly in these images since etching rates of Bore-doped stress rods is higher than pure silica. We adopted the pre-defined fixed threshold value in image binarization processing. An adaptive threshold value has also been tested for binarization processing to reduce noises and interferences. In each image, the average background value and the noise value are computed and we used the value (threshold value = average background value +2xnoise value) as dynamic threshold value. Noises in the image are filtered by a smoothing processing (fig 3.a.2). The threshold filter used for image binarization shows clearly the darkness of the etched stress rods of the polarization Maintaining optical fiber (fig 3.b.2). The background (figure 3.a.1) is subtracted from the image of etched fiber and only optical fiber probe etching information remained (figure 4).

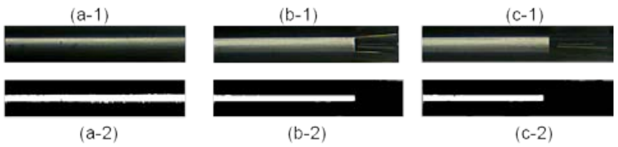

FIG. 3 (a.1) NON ETCHED PM FIBER (b.1) PM FIBER AFTER 5 MIN OF HF ETCHING. (b.2) PM FIBER AFTER 10 MIN OF HF ETCHING (a.2), (b.2), (c.2) BINARIZATION OF MICROSCOPE IMAGES WITH FIXED THRESHOLD

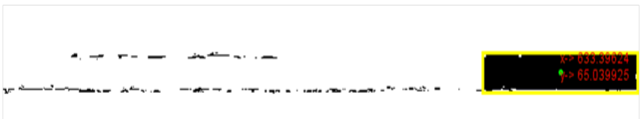

FIG. 4 SUBTRACTION OF MONO-IMAGES 3.a.2 and 3.b.2 AND BLOB DETECTION

After rectification, image contour processing is used to detect the existence of blobs. The size, coordinate value of center point of each blob in the optical fiber probe image can be calculated respectively. A selective mode of blobs based on weight discrimination is used to avoid detection of noise. Hence only etching information remains as blobs. Figure 4 is the subtraction of the background non-etched optical fiber image (fig 3.a.1) and the etched optical fiber image figure (3.b.1). In particular, figure 4 shows stress rods etching processed images used for etching rates characterisation. Weight selection blobs algorithm allows avoiding detection of noise zones principally emerging from low focal distance fluctuation. As illustrated, the only detected blob appearing in the image is the etched stress rods of etched optical fibre. In this study, a blob function of OpenCV [8] is called for detection of blobs on binary images for which background has been subtracted. A centroid calculation algorithm is used in the study to calculate the coordinate value of center point of the blob. Tracking of centroid of multiple etched images allow the tracking of etching rates and precise control of the fabrication process of polarization maintaining optical fiber evanescent-wave sensor. The Distribution of the chemical etching rates in the fiber profiler simulator is defined as:

$$V(x,y) = \begin{cases} Vs & if\ (y-\delta)^2 + x^2 \leq r_s \\ Vs & if\ (y+\delta)^2 + x^2 \leq r_s \\ Vc & Otherwise \end{cases} \qquad (1)$$

Where Vc and Vs are respectively the etching rates of cladding and stress rods. The profile of the fiber during the chemical etching is given by the simulator as shown in the Fig.2.

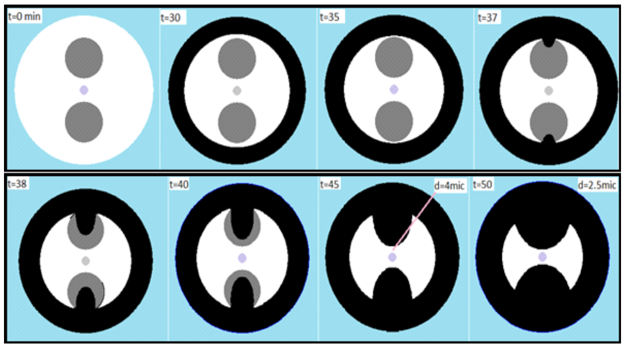

FIG.5 SIMULATION OF THE TRANSVERSE SECTION OF ETCHED PANDA PM FIBER DURING CHEMICAL ETCHING

Matched refractive index liquid has been dropped on the fibre to characterize optically the sensitivity of fabricated sensors. In order to analyze the repeatability of the fiber sensor, the attenuated optical power is detected. The cladding thickness is then derived from the theoretical model of Leminger and Zengerle [9]. We found an excellent experimental repeatability higher than 0.2dB even in a dynamic parameters environment.

Sensitivity Reproducibility Tests

Several theoretical models have been developed for giving an expression of light attenuation inside polished optical fibers as a function of the cladding thickness such as Vasallo [21], Leminger and Zengerle [22], and Sharma et al [23]. These models describe the correlation between the linear attenuation coefficient and the remained cladding thickness of a polished single mode optical fiber based on coupling theory between the fundamental mode of the single-mode fiber and the radiation modes in the external Medium. Hence cladding thickness of etched singe mode fibers

can be deduced from measurements of linear attenuation coefficient. In this part, the reproducibility of the sensitivity of etched polarization maintaining optical fibers sensors is deduced from the measurement of the linear attenuation coefficient. A refractive index matched liquid is dropped on the etched surface of polarization maintaining fibers and the linear attenuation coefficient is experimentally measured. A pigtailed optical light source at 1550 nm wavelength is injected in the device under test and the output optical power is measured by using an InGaAs photodiode based optical power meter calibrated at 1550nm. The fiber sensor fabrication process is controlled precisely as described in paragraph 2. Fig. 6 shows the standard deviation of sensitivity histogram as a function of the etched PM fiber linear attenuation coefficient.

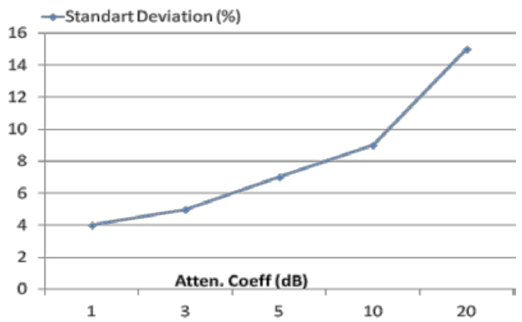

FIG.6 SENSITIVITY STANDART DEVIATION AS A FUNCTION OF ATTENUATION COEFFICIENT

Conclusions

We have presented a new method for determining the cladding thickness of etched (PM) fiber type PANDA under the same operating conditions and manufacturing of the sensor. The comparison between the experimental and the theoretical data show that the cladding thickness is determined by a maximum error that not exceed 0.4 µm. the major advantage of this method is the knowledge of the cladding thickness of the sensor during its chemical etching without disturbing the fabrication process.

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